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Contact problem at mill semi finished items with the account of the thermal emission and forces in knife grinding machines

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Abstract. Knife grinding machines – the basic process equipment for mill fibrous materials in a pulp and paper industry. In article the forces arising knife gap a backlash at mill chip and fibrous weight of high concentration are investigated. It is centrifugal force, force of friction of a semi finished item about grinding disks, force of pressure steam and axial force. Steam can promote promotion or, on the contrary, braking of movement of a semi finished item in knife gap a backlash. The contact task is considered and solved in view of a thermal emission in a zone mill. Formulas for definition of contact temperatures in a zone mill are received. Settlement values of temperature prove to be true experimental researches. The maximal temperature in a zone of contact is observed in a zone 0.50-0.70 radiuses sets. This zone coincides with a zone of the maximal pressure in which there is a zone of zero speed steam. Current steam is investigated in the field of contact of a rotor and stator. Conditions of movement pair from a zone of zero speed steam to periphery and to the center of grinding disks are revealed. Movement pair to the center of grinding disks is undesirable. Thus productivity of a mill decreases and hydrodynamic impacts grow by elements of a design of a mill. Such mode of movement steam depends on technological and regime factors mill and quite often arises at mill chips in manufactures of a thermomechanical and chemical-thermomechanical wood pulp. The steam is recommended to delete directly from a zone of zero speed.

1. Introduction

Knife grinding machines - the basic process equipment for mill fibrous materials in a pulp and paper industry. Power of the drive of these machines reaches tens of megawatts. Efficiency of the knife grinding machines does not exceed one percent [1]. At grind of spill and mass of high concentration a lot of steam [1, 2] which is used further in production is emitted. The relevance of researches is confirmed by a set of publications of pilot studies of thermal emission at grind [3-6]. In article the attempt to consider a contact task at grind [7] taking into account thermal emission is for the first time made. The contact problem at mill semi finished items in view of a thermal emission and forces in knife grinding machines will consist of three parts: definitions of distribution of temperature on radius sets; definition of forces in intestine knife a backlash; definition of the pressure arising from thermal deformation of details of a mill. The technique of definition of temperature pressure in set of a mill is developed in work [8].

In intestine knife a backlash knife grinding machines the fibrous semi finished item is exposed to influence of normal, radial and tangential forces [1-3]. The purpose of article is the research of contact



thermal emission and development of techniques and recommendations at design and modernization of the knife grinding machines.

2. Methods and Materials

Using “a principle of a microscope” [9] we shall stretch a vicinity of a point of contact of a knife of a rotor and stator and we shall present the circuit of contact (Figure 1). At researches we count, that rotor and stator disks – absolutely rigid bodies, knives sets of a rotor and stator are parallel also area of contact much more surpasses intestine knife a backlash between a rotor and stator.

Let at the moment of time $t = 0$ rotor starts to rotate concerning axis Y with constant speed ω (Figure 1), and stator remains motionless. In the field of contact stator and rotor there are the forces $F(t)$ connected by contact pressure $p(t)$ by nonlinear dependence $F(t) = k(p)$. Let's allocate a ring dr a fibrous semi finished item in weight dm areas of contact in intestine knife a backlash S we will also consider forces operating on a semi finished product (Figure 2).

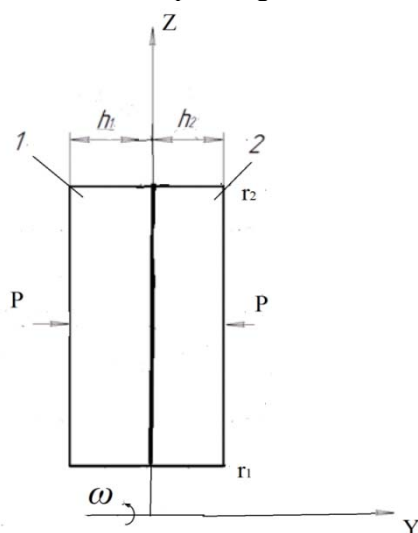


Figure 1. The circuit of contact of knives of a rotor and stator: 1 – stator; 2 – rotor

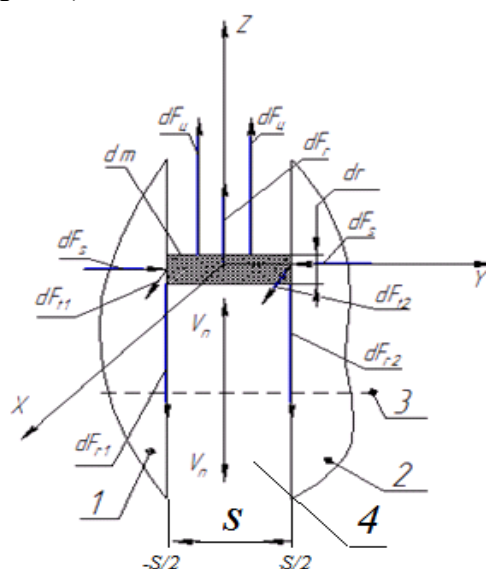


Figure 2. Forces, working on a semi finished item: 1 – stator; 2 – rotor; 3 – zone of zero speed steam; 4 – a fibrous layer

3. Calculations

3.1 Forces arising in intestine knife a backlash

The radial force promoting moving of a semi finished item on radius sets

$$dF_r = dF_c - dF_{r1} - dF_{r2} \pm dF_n, \quad (1)$$

where dF_c – centrifugal force; dF_{r1} , dF_{r2} – force of friction of a semi finished item about stator and rotor disks; dF_n – force of influence steam on a semi finished item. “+” in the formula (1) it is used when steam promotes movement of a semi finished item to periphery sets, and “–” when steam movement of a semi finished item brakes.

Force of influence steam on a semi finished item depends on a degree of compression of a semi finished item which in turn depends from intestine knife a backlash and a degree of his filling. As this force depends from elastoviscous characteristics of the semi finished item [1, 2, 5-7]. Steam on a semi finished item in directions X , Y , Z it is possible to write down force of influence as

$$dF_{nx,ny,nz} = f_n \rho_n(r) [V_n(r)]^2 A(r)_{x,y,z} dm \quad (2)$$

where f_n – factor of friction between the ferry and a semi finished item; $\rho_n(r)$ – density steam on radius r ; $V_n(r)$ – speed steam on radius r ; $A(r)_{x,y,z}$ – an aerodynamic surface of a ground semi finished item on radius r in directions X, Y, Z ; dm – weight of a semi finished item on an infinitesimal ring intestine knife a backlash.

The centrifugal force working on a semi finished item

$$dF_c = \omega^2 r dm \quad (3)$$

where ω – angular speed of rotation of a rotor; r – the current radius sets.

Force of friction of a semi finished item about disks in a radial direction

$$dF_{r1,2} = dF_{r1} + dF_{r2} = 4f_r \pi r p(r) dr \quad (4)$$

where f_r – factor of friction of a semi finished item about set in a radial direction; $p(r)$ – axial pressure upon a semi finished item upon radius r . Definition of this pressure is executed in works [1, 4, 6, 10-14]. This pressure depends on properties of a semi finished item and his characteristics loading.

Force of friction of a semi finished item about disks in a tangential direction

$$dF_t = dF_{t1} + dF_{t2} = 4\pi f_t p(r) r dr \quad (5)$$

where f_t – factor of friction of a semi finished item about set in a tangential direction.

Capacity for overcoming tangential and radial forces of friction of a semi finished item about set

$$N_{t,r} = \int_{r1}^{r2} 4\pi f_t r p(r) \omega r^2 dr \quad (6)$$

The axial force working on a semi finished item in an axial direction

$$F_s = \int_{r1}^{r2} 2\pi p(r) r dr + \int_{r1}^{r2} dF_{ny} dr \quad (7)$$

The force working on a semi finished item in a radial direction

$$F_r = \int_{r1}^{r2} 4\pi f_r r p(r) dr + \int_{r1}^{r2} dF_{nz} dr \quad (8)$$

The force, working on a semi finished item in a tangential direction

$$F_t = \int_{r1}^{r2} 4\pi f_t r p(r) dr + \int_{r1}^{r2} dF_{nx} dr \quad (9)$$

where dF_{ny} , dF_{nz} , dF_{nx} – force influences steam on a semi finished item dm accordingly in directions Y, Z, X .

Total force working on a semi finished item in the field of contact of a rotor and stator $\vec{F} = \vec{F}_s + \vec{F}_r + \vec{F}_t + \vec{F}_c = \vec{k}(p)$, where k – nonlinear factor, p – pressure in a zone of contact.

Steam goes from the center of a disk (Figure 2) to his periphery at

$$\vec{F}_c > \vec{F}_t + \vec{F}_r \quad (10)$$

and from periphery to the center of a disk at

$$\vec{F}_c < \vec{F}_t + \vec{F}_r \quad (11)$$

Current of a fibrous semi finished item and steam in intestine knife a backlash disk in knife grinding machines: is shown in Figure 3.

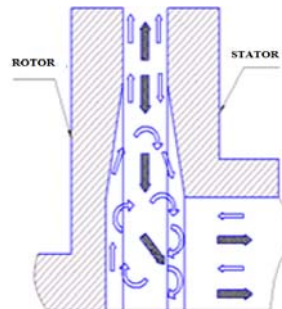




Figure 3. Current of a fibrous semi finished item and steam in intestine knife a backlash disk in knife grinding machines:  – a semi finished item (chips);  – steam.

3.2. Contact problem in view of a thermal emission in a zone mill

For definition of contact temperature it is necessary to define contact temperatures of surface sets of a rotor and stator. For this purpose it is necessary to consider a problem of heat conductivity of a rotor and stator at presence of sources of heat in a zone of their contact, i.e. on an axis Z (Figure 1). Actually the thermal emission occurs not on an axis Z , and in a thin layer between a rotor and stator. Thermal properties of this layer where there is a ground fibrous material, rather it is not homogeneous on thickness. So that correctly to formulate boundary conditions of a problem of heat conductivity in a layer between a rotor and stator mills, it is necessary to solve all over again a problem of heat conductivity for non-uniform on thermal to properties of a layer of thickness s with the sources of heat distributed in it.

If to neglect a small share of capacity of work of forces of the friction, going on deterioration and elastic deformation of a rotor and stator the quantity of heat Q allocated in unit of time on unit of the area a constant, it is possible to present the formula [15]:

$$Q = VF(t) = Vk(p) \quad (12)$$

where V – speed of sliding of knives of a rotor on knives stator.

Let's consider the one-dimensional equation of heat conductivity:

$$[\lambda(y)T'(y)]' = -f(y) \quad (13)$$

where $T'(y)$, $\lambda(y)$, $f(y)$ – temperature, factor of heat conductivity and the distributed sources of heat of a fibrous layer.

Let's consider boundary conditions on borders of a layer:

$$\text{at } y = -s/2, T = T_1, \lambda(s/2)T' = \lambda_1 T'_1, \quad (14)$$

$$\text{at } y = -s/2, T = T_2, \lambda(-s/2)T' = \lambda_2 T'_2, \quad (15)$$

where T_1 and T_2 – temperature stator and rotor; λ_1 , λ_2 – factors of heat conductivity of materials stator and rotor.

Conditions (14) and (15) are usual conditions of equality of temperatures and streams of heat between contacting bodies. We shall notice, that $\lambda(-s/2) = \lambda_2$ and $\lambda(s/2) = \lambda_1$ by virtue of a continuity of transition thermal properties of a layer to thermal to properties of a rotor and stator on borders $y = -s/2$ and $y = s/2$. It is logical to write down, that

$$\int_{-s/2}^{s/2} f(\eta) d\eta = Q \quad (16)$$

where Q it is defined by expression (12). Integrating the equation (13) once and taking into account conditions (14) and (15) we shall receive

$$\lambda_2 T'_2 - \lambda_1 T'_1 = Q = Vk(p) \quad (17)$$

Integrating the equation (13) again in view of conditions (14) and (15)

$$T_1 - T_2 = -\int_{-s/2}^{s/2} f(\eta) d(\eta) \int_{\eta}^s \frac{dy}{\lambda(y)} + \lambda_2 T'_2 \frac{s}{\lambda_0} \quad (18)$$

where $\frac{1}{\lambda_0} = \frac{1}{s} \int_{-s/2}^{s/2} \frac{d\eta}{\lambda(\eta)}$.

Estimating the right part of expression (18), it is possible to write down

$$T_1 - T_2 \leq \lambda_2 T'_2 \frac{s}{\lambda_0} \quad (19)$$

$$T_1 - T_2 \geq -Q \frac{s}{\lambda_0} + \lambda_2 T'_2 \frac{s}{\lambda_0} = \lambda_1 T'_1 \frac{s}{\lambda_0} \quad (20)$$

As the backlash s between sets of a rotor and stator is small, we shall accept for $T_1 - T_2$ average value between the top and bottom estimations. In result we shall receive a known [16] condition for no ideal thermal contact

$$\lambda_2 T_2' + \lambda_1 T_1' = \frac{2}{r} (T_1 - T_2), \quad (21)$$

where $r = \frac{s}{\lambda_0}$ – contact resistance. The more pressure $p(t)$, the more densely contact of a rotor and stator and is less r , i.e. $r = r(p)$, where $r(p)$ – monotonously decreasing function. For simplicity of calculations we count, that r – a constant.

Let's consider a problem with disks with fixed on them plate. At $y = -s/2$ we shall accept conditions (17) and (21). At an idle mill the temperature of a rotor and stator is constant and equal to an ambient temperature. This temperature can be accepted for a reference mark, i.e. $T_0 = 0$, signify $T_1 = 0$ at $y = h_1$ and $T_2 = 0$ at $y = -h_2$. Temperatures stator and a rotor in the field of contact we shall designate accordingly through T_1^k , T_2^k . Then from the equations of heat conductivity sets $T_i'' = 0$ ($i = 1, 2$) we shall find temperatures of a rotor and stator

$$T_1 = T_1^k \left(1 - \frac{y}{h_1}\right), \quad T_2 = T_2^k \left(1 + \frac{y}{h_2}\right) \quad (22)$$

$$T_1^k = \frac{Vk(p)h_1(\lambda_2 r + 2h_2)}{2(\lambda_1 \lambda_2 r + \lambda_2 h_1 + \lambda_1 h_2)}, \quad T_2^k = \frac{Vk(p)h_2(\lambda_1 r + 2h_1)}{2(\lambda_1 \lambda_2 r + \lambda_2 h_1 + \lambda_1 h_2)} \quad (23)$$

Results of calculations of change of temperature on radius sets of a rotor and stator at mill fur-tree chips on a mill with radius of a disk 750 mm and peak pressure in a zone of contact $p = 100$ MPa are submitted in figure 4. Settlement values of temperature prove to be true experimental researches [17-21].

Mechanical and thermal properties of materials of a rotor and stator, as a rule, are identical. The maximal temperature in a zone of contact is observed in a zone 0.50-0.70 radiuses disk knife grinding machines. This zone coincides with a zone of the maximal pressure steam in which there is a zone of zero speed steam. Steam from this zone can move to periphery or to the center of grinding disks (Figure 4), depending on conditions (10) and (11). Movement steam to the center of grinding disks is undesirable, productivity of a mill decreases and hydrodynamic impacts grow by elements of a design of a rotor and stator. Such mode of movement steam depends on technological and regime factors mill and quite often arises at mill chips in manufactures of a thermomechanical and chemical-thermomechanical wood pulp. Therefore, for elimination of this mode the steam is recommended to delete steam directly from a zone of zero speed.

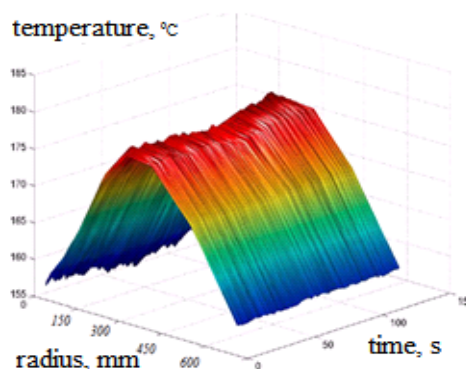


Figure 4. Change of temperature in a zone of contact of a rotor and stator at mill fur-tree chips in a mill in knife grinding machines.

4. Conclusions

Techniques for definition of temperature and forces are developed and approved at mill in knife grinding machines.

The maximal temperature in a zone of contact is observed in a zone 0.50-0.70 radiuses disk knife grinding machines. And the zone of the maximal temperatures in a zone of contact coincides with a zone of zero speed steam.

Current steam is investigated in the field of contact of a rotor and stator. Conditions of movement steam from a zone of zero speed steam to periphery and to the center of grinding disks are revealed.

The steam for reduction of hydrodynamic impacts by elements of a design of a mill is recommended to delete steam directly from a zone of zero speed.

References

- [1] Goncharov V N 1990 Theoretician's potters of a basis mill fibrous materials in knife grinding machines (Auth. abstr. dis. compet. dr. sci. tech. L) p 31
- [2] Miles K B 1998 The essence of high consistency refining (*Marcus Wallenberg Foundation Symposia Stockholm Sweden*) pp 20-30
- [3] Berg J K, Sandberg C, Engberg B A 2015 Low consistency refining of mechanical pulp in the light of forces on fibers *Nord. Pulp Pap. Res. J.* **30** (2) 225
- [4] Rajabi N N, Olson J A, Heymer J, Martinez M D 2014 Understandnig of No-load Power in Low Consistency Refiners *The Canadian Journal of Chemical Engineering* **92** (3) 524
- [5] Hafren J, Fernando D, Gorski D, Daniel G 2014 Fiber and fine fractions-derived effects on pulp quality as a result of mechanical pulp refining consistency *Wood Sci. Technol.* **48** (4) 737
- [6] Karlstrom A, Eriksson K 2014 Fiber energy efficiency Part II: Forces acting on the refiner bars *Nord. Pulp Paper Res. J.* **29**(2) 332
- [7] Vikharev S N 2013 Contact interaction sets of mills with a fibrous finished item. *Wood magazine.* **3** 133
- [8] Vikharev S N 2007 Research of temperature pressure sets of disk mills. *Cellulose, paper, cardboard.* **12** 57
- [9] Tcherepanov G P 1974 Mechanics of fragile destruction (Moscow Science) p 640
- [10] Mills K B 1995 Wood characteristics and energy consumption in refiner pulps. *J. Pulp. Pap. Sci.* **21** **11** I 383
- [11] Alashkevich J D, Kovalev V I and Nabieva A A 2010 Influence of figure sets on process mill fibrous semi finished items Monographic in 2 parts (Part 1 Krasnoyarsk) p 168
- [12] Alashkevich J D 1986 Bas of the theory of hydrodynamic processing of fibrous materials in mill machines (Auth. abstr. dis. compet. dr. sci. tech. Krasnoyarsk) p 36
- [13] Olender D Wild P 2007 Forces on Bars in High-Consistency Mill-Scale Refiners. Trends in Primary and Rejects Stage Refiners. *J. Pulp Paper Sci.* **33** (3) 163
- [14] Senger J, Olmstead M, Ouellet D 2004 Measurement of Shear and Normal Forces in the Refining Zone of a TMP Refiner. *J. Pulp Paper Sci.* **30** (9) 247
- [15] Aleksandrov V M and Chebakov M I 2007 Introduction in mechanics of contact interactions (Rostov- on-Don publishing house of Open Company TSVVR) p114
- [16] Podstrigach J S 1963 Temperature a field in system of the firm bodies connected to the help of a thin intermediate layer. *J. Science* **6** (10) 129
- [17] Gorski D, Hill J, Engstrand P, Johansson L 2010 Reduction of energy consumption in TMP refining through mechanical pretreatment of wood chips. *Nord. Pulp Pap. Res. J.* **25** (2) 156
- [18] Miles K B, Omholt I 2008 The origin and control of pulp stress during high-consistency Refining. *J. Pulp Pap. Sci.* **34** (3) 169
- [19] Muhic D, Sundstrom L, Sandberg C, Ullmar M, Engstrand P 2010 Influence of temperature on energy efficiency in double disc chip refining. *Nord. Pulp Pap. Res. J.* **25** (4) 420
- [20] Muhic D, Huhtanen J P, Sundstrom L 2011 Energy efficiency in double disc refining-Influence of intensity by segment design. *Nord. Pulp Pap. Res. J.* **26** (3) 224
- [21] Muhic D, Sundstrom L, Sandberg C, Ullmar M, Engstrand P 2010 Influence of temperature on energy efficiency in double disc chip refining. *Nord Pulp Pap. Res. J.* **25** (4) 420